3.2.5. MLO AND BOULDER UV SPECTRORADIOMETERS

Solar radiation measured at the Earth's surface depends on the absorption and scattering of the atmosphere, the Earth-Sun distance, and the irradiance of the Sun. The UV portion of the spectrum is controlled primarily by Rayleigh scattering by air molecules, scattering by clouds, and absorption by ozone. Under clear-sky conditions, at a given site and for a given solar zenith angle (SZA), variations in UV are strongly correlated (inversely) with variations in total ozone. As part of the Network for the Detection of Stratospheric Change (NDSC) a UV spectroradiometer (labeled UVL) was installed at MLO (19.533ºN, 155.578ºW, 3.4 km) in July 1995. This instrument operated until June 1997, and a new instrument (UV3) was installed in November 1997 and continues in operation at MLO to the present.

To provide an additional site for these studies, a UV spectroradiometer (UVL, the same instrument initially installed at MLO) was installed at the Boulder laboratory (39.991°N, 105.261°W, 1.62 km) in June 1998. This instrument was replaced with a new instrument (UV4) in September 1999. Finally, the UV4 instrument was replaced with another new instrument (UV5) in August 2001. Of note is the fact that UV5 participated in an instrument comparison at the Table Mountain, Colorado, research site during June-July 2001, immediately before it was installed in Boulder. This instrument has continued in operation at Boulder to the present. All of these instruments (UVL, UV3, UV4, UV5) were constructed by the National Institute of Water and Atmosphere (NIWA) group at Lauder, New Zealand, under a cooperative program agreement with CMDL. The various spectroradiometers used at MLO and Boulder are summarized in Table 3.9. The goal of this program is to study the relationship between UV and ozone and to determine long-term trends, if any, in UV. MLO and Boulder are both excellent sites for this study because of the prevalence of clear skies and the collocation of Dobson ozone spectrophotometers.

Data analysis is accomplished through the use of software provided by the NIWA-Lauder research group. This software runs on IBM PC-type machines and is designed to read the raw monthly data files, apply calibrations, and calculate a UV spectrum for each observation. The program asks for instrument name

(such as UVL), year, month, and block number as input while running, and therefore it is necessary to know which instrument was located at a particular location and time in order to process the data. The program automatically calculates certain integrated spectra such as UVB, UVA, and erythema, and has the capability of calculating any special action spectrum, such as deoxyribonucleic acid (DNA) or vitamin D. The erythema spectrum [*McKinlay and Diffey*, 1987] is important because it represents the response function of human skin to UV radiation, and it is used in studies of sunburning. The vitamin D spectrum [*MacLaughlin et al.*, 1982] is important because exposure to sunlight causes the photosynthesis of vitamin D in human skin. In this report results are presented only for erythema because at the time of this writing there is no general agreement among researchers on the correct vitamin D spectrum for use in these calculations.

UV data from MLO were presented by *Bodhaine et al.* [1996, 1997], *McKenzie et al.* [2001], and briefly in *CMDL Summary Reports No. 23, 24, and 25* [*Hofmann et al.*, 1996, 1998; *Schnell et al.*, 2001]. The UV irradiances measured at MLO are much larger than at low-altitude midlatitude locations, primarily because of less Rayleigh scattering, but also because of lower column ozone in the subtropics. Boulder can be considered a midaltitude site, since it lies about half-way between MLO and sea level. Here the complete data set is presented, selected for clear mornings at MLO, and clear mornings and afternoons at Boulder. Clear mornings occur at MLO approximately 60% of the time, providing an excellent site for solar radiation measurements. Clear skies occur less often, and UV data tend to be noisier, at Boulder. Clear afternoons are accepted in addition to clear mornings at Boulder in order to increase the number of data points. All processed spectral data are available from the solar radiation division of the CMDL program.

Instrumentation

The UVL spectroradiometer was described by *McKenzie et al.* [1992] and *Bodhaine et al.* [1997]. Briefly, a diffuser designed to minimize cosine error and machined from Teflon is mounted as a horizontal incidence receptor to view the whole sky. For UVL, stepper-motor-driven gratings cover the spectral range of 290-450 nm in a single scan with a bandpass of about 1 nm. The newer instruments (UV3, UV4, and UV5) cover the range 285-450 nm with a bandpass of about 0.8 nm, and use fiber optic cables to transmit the light from the sensor to the spectrometer. A complete forward scan for UVL requires about 3 min. The UV3, UV4, and UV5 instruments do a backward scan and then a forward scan centered at the desired SZA, and therefore require about 6 min for a complete measurement. All instruments are programmed to perform scans every 5° of SZA during daytime hours, starting at 95° SZA in the morning and ending at 95° SZA in the afternoon. During midday for 2.5 hours the sampling interval is changed to once every 15 min because the SZA changes slowly during that time.

Absolute calibrations of the spectroradiometers are performed at approximately 6-mo intervals with 1000-W FEL lamps traceable to NIST standards. A dedicated

TABLE 3.9. UV Spectroradiometers at MLO and Boulder

Instrument	Date
MLO	
UVL	July 1995–June 1997
UV3	November 1997–present
Boulder	
UVL	June 1998–September 1999
UV4	September 1999–August 2001
UV5	August 2001–present

calibration bench is set up at MLO for these calibrations. The Boulder instrument is calibrated by NOAA's Surface Radiation Research Branch (SRRB) with a portable 1000-W lamp calibrator. Weekly stability calibrations are performed at both sites with mercury lamps for wavelength calibration and 45-W standard lamps for long-term stability checks. The long-term accuracy of the spectroradiometer systems is expected to be better than ±5%.

Data Analysis

For the following analyses, UV spectroradiometer data for 45° and 65° SZA were chosen for clear mornings at MLO during the July 1995-October 2001 time period. This gives approximately 6.5 years of data, and includes ozone values in the range of about 200-350 Dobson units (DU). For Boulder data, 65° SZA and the period July 1998-October 2001 were used, covering an ozone range of about 220-400 DU. Note that 45° and 65° are the smallest SZAs attained year round at the MLO and Boulder sites, respectively. The 65° SZA data are used for comparisons between MLO and Boulder. Clear mornings at MLO and Boulder were determined in the same manner as in previous studies; that is, a day was accepted as a clear day at MLO if the sky was cloudless from dawn through the time of the desired scan, and if Dobson ozone data were available for that morning. At Boulder, generally, the sky had to be clear at the time of the scan, Dobson ozone data had to be available, and clear afternoons were also accepted. The Dobson ozone observation closest to the time of the UV scan was used. Figures 3.20 and 3.21 show MLO ozone and UV erythema data for July 1995-October 2001 for 45° and 65° SZAs, respectively. Figure 3.22 shows similar data for Boulder for June 1998-October 2001 for 65° SZA. Erythemal radiation data were obtained from the spectroradiometer data for both sites by applying the erythemal weighting function of *McKinlay and Diffey* [1987] and integrating over wavelength for each scan, as discussed by *Bodhaine et al.* [1997]. The inverse relationship of UV erythema and ozone at both sites is apparent.
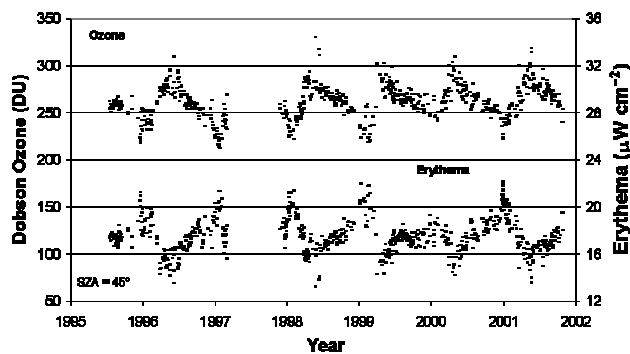

Fig. 3.20. Erythemal irradiance at 45° SZA (bottom) and total ozone (top) for clear-sky mornings at MLO over the time period July 1995-October 2001.
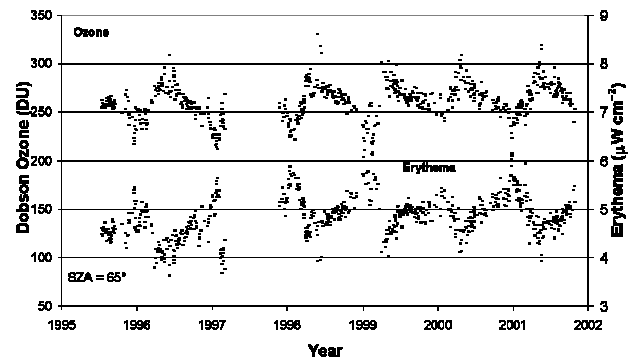

Fig. 3.21. Erythemal irradiance at 65° SZA (bottom) and total ozone (top) for clear-sky mornings at MLO over the time period July 1995-October 2001.
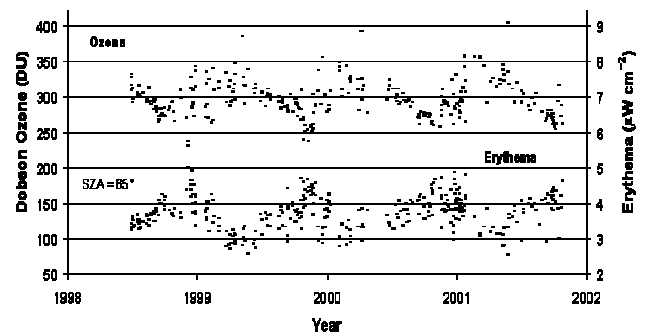

Fig. 3.22. Erythemal irradiance at 65° SZA (bottom) and total ozone (top) for clear-sky mornings and afternoons at Boulder over the time period June 1998-October 2001.

Figures 3.23 and 3.24 show the relationships between UV erythema and ozone at MLO for November 1997-October 2001 for 45° and 65° SZAs, respectively, corresponding to the most recent instrument configuration. Figure 3.25 shows the relationship between UV erythema and ozone at Boulder for the time period June 1998-October 2001 for 65° SZA. The radiative amplification factor (RAF), defined as the percent change of UV (erythemal) irradiance divided by the percent change of total ozone, was calculated for both sites, using the power-law formulation of *Madronich* [1993]: RAF = $-\Delta\ln(I)/\Delta\ln(O_3)$, where I is UV irradiance. The RAF is simply the slope of a straight-line fit on a log-log plot. The data for Boulder are subject to more scatter because of more variable sky conditions than at MLO. The scatter in the Boulder data can be reduced significantly by plotting the ratio of erythemal to 340-nm irradiance against ozone. Since ozone effects are essentially absent at 340 nm, this reduces the effects of aerosols, clouds, and other atmospheric variations.

Figure 3.26 shows the RAF at MLO as a function of wavelength for SZAs of 45° and 65°. In general the RAF decreases with increasing wavelength, and the ozone
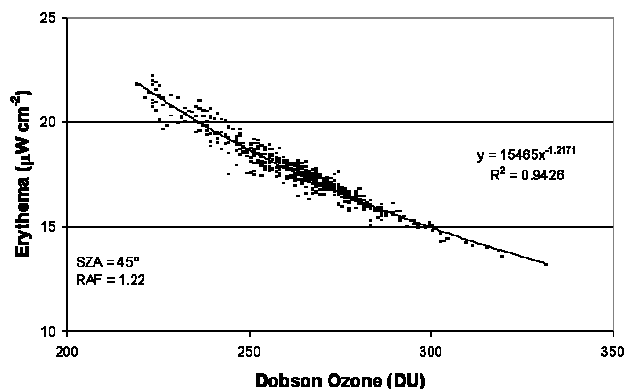
Fig. 3.23. Power law regression between erythemal irradiance at 45° SZA and Dobson total ozone at MLO over the time period November 1997-October 2001. The graph is plotted on a linear scale to facilitate reading the units. The exponent of the power law function (1.22) gives the RAF.
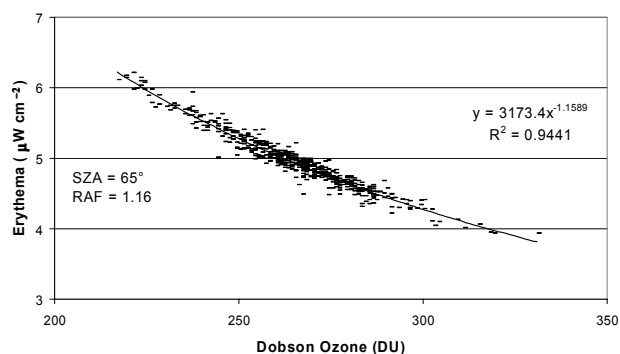

Fig. 3.24. Power law regression between erythemal irradiance at 65° SZA and Dobson total ozone at MLO over the time period November 1997-October 2001. The graph is plotted on a linear scale to facilitate reading the units. The exponent of the power law function (1.16) gives the RAF.
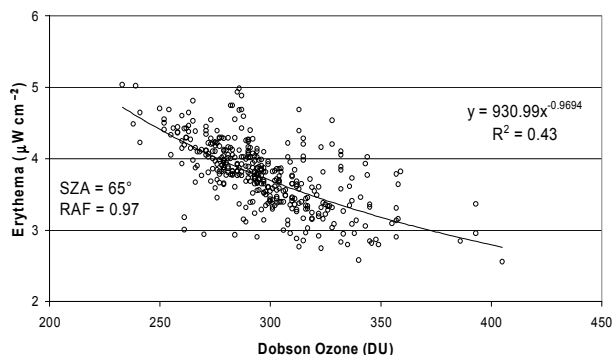

Fig. 3.25. Power law regression between erythemal irradiance at 65° SZA and Dobson total ozone at Boulder over the time period June 1998-October 2001. The graph is plotted on a linear scale to facilitate reading the units. The exponent of the power law function (0.97) gives the RAF.

dependence is negligible for 340 nm. It is clear from the figure that the RAF is consistently larger for larger SZAs. Figure 3.27 shows the RAF at MLO as a function of SZA for SZAs in the range 15°-85°. The apparent break in the slope of the data for SZAs <35° is most likely caused by the fact that smaller numbers of data points are available for SZAs of 15°-35° because these smaller SZAs are not reached during winter months, which means that somewhat different ranges of ozone data are used for those data points.

Conclusions

- Erythemal irradiance calculated from UV spectra at MLO and Boulder is inversely correlated with Dobson total ozone.
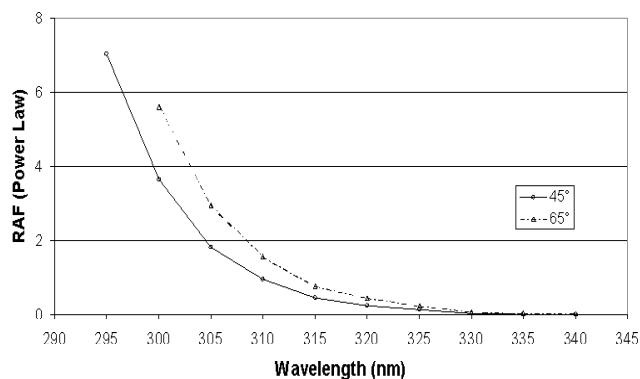- No significant trend in UV irradiance may be inferred because of the limited time period.

Fig. 3.26. Erythema RAF as a function of wavelength at MLO for 45° and 65° SZAs for November 1997-October 2001.
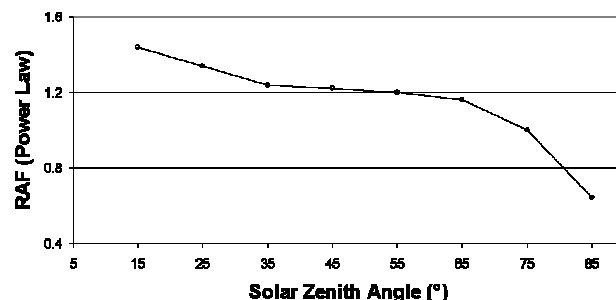

Fig. 3.27. Erythema RAF as a function of SZA at MLO for November 1997-October 2001.